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The Earth Observing System Terra Series

These articles focus on the overarching science priorities of the EOS Terra mission
http://terra.nasa.gov

Changing Global Land Surface

Human presence across the face of the Earth is substantial and growing. Increasingly, from the perspective of outer space we can see the “fingerprints” of human presence on our landscapes. From the herringbone patterns of tropical deforestation, to the large square patches of agricultural fields, to the concrete splotches of urban sprawl, humans have attained the magnitude of a geological force as we reshape our environments. Scientists estimate that between one-third and one-half of our planet's land surface has been transformed by human enterprises. Yet, scientists cannot say what, if any, long-term impacts these changes will have on global climate systems.

Since the industrial revolution, scientists have observed a continued and accelerating rise in the levels of greenhouse gases in the atmosphere (Figure 1). Of particular concern is the increase in the buildup of carbon dioxide, which is a direct result of urban consumption of fossil fuels as well as the widespread use of fires in the tropics for deforestation. Over the last century, scientists have measured a 0.5-degree rise in average global temperatures that is due, at least in part, to increased levels of greenhouse gases. How will land plants respond to these changes in temperature and carbon dioxide levels? Will they delay or accelerate the global warming trend? Will plant biomes (e.g., forests, tundra, and grasslands) move in response to climate change? Will the world's ice sheets and glaciers retreat northward as warmer climates move to higher latitudes? Scientists cannot answer these questions now. But with the launches of NASA's Landsat 7 and Terra satellites, unprecedented new data becomes available

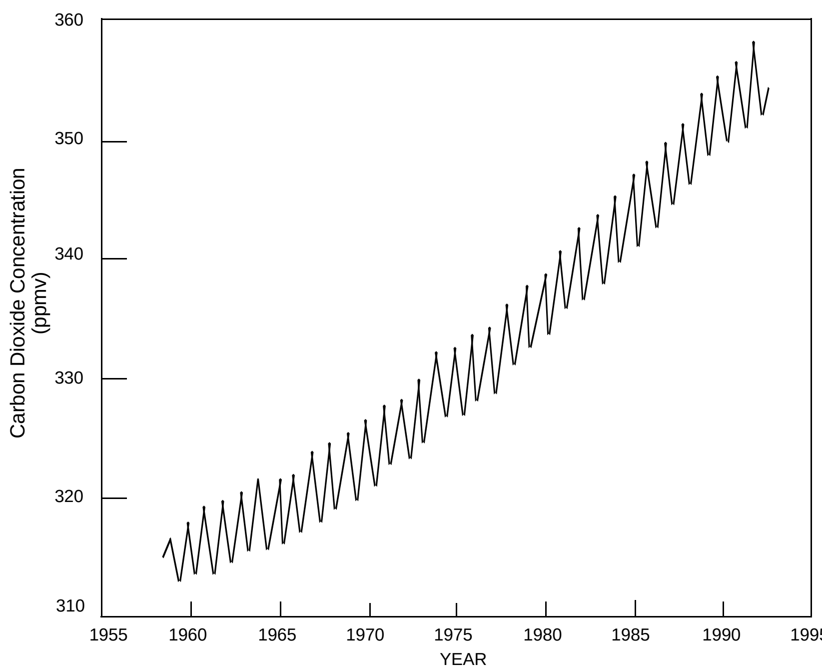

Figure 1. Average carbon dioxide (CO_2) concentration in parts per million by volume (ppmv), observed continuously at the Mauna Loa Observatory in Hawaii. Atmospheric CO_2 , a major greenhouse gas, has increased approximately 40 ppmv since 1958, largely because of human activities. Superimposed on the long-term increase is the annual cycle due to photosynthetic activity (data archived at Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory).

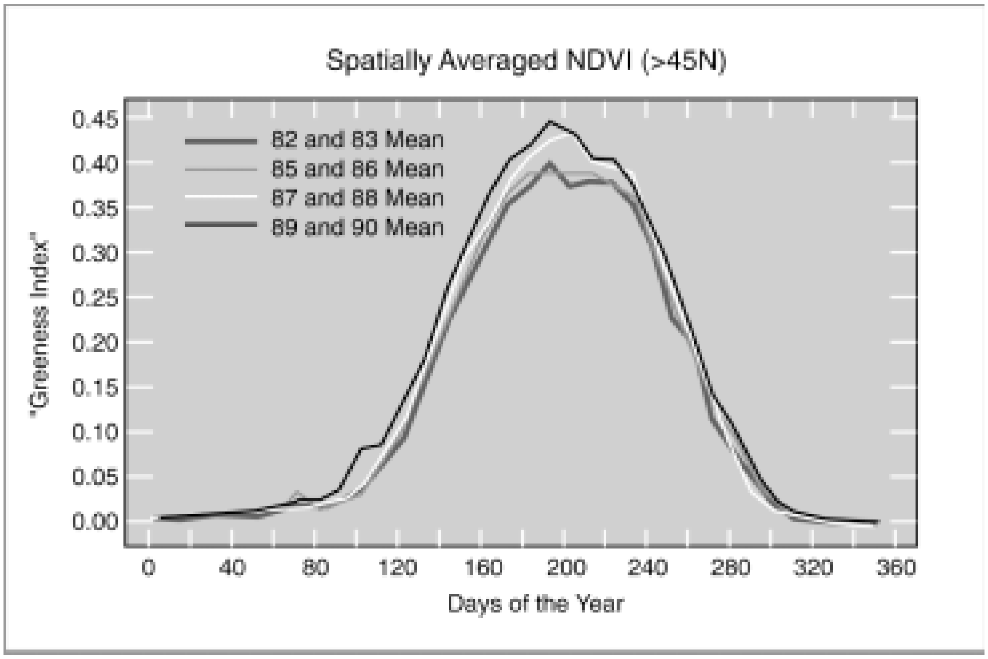

Figure 2. Analysis of satellite data indicating that the Northern Hemisphere growing season has lengthened during the 1982-1990 period. The vertical axis corresponds to a “greeness index” of vegetation activity, called the Normalized Difference Vegetation Index (NDVI).

to scientists around the world that will help them better understand and predict how Earth’s changing land surfaces affected climate, as well as how climate changes will further cause land surfaces to change.

The Carbon Cycle

As atmospheric concentrations of carbon dioxide continue to increase, the Earth’s climate is expected to change significantly over the next several decades. In response, scientists expect to see gradual shifts in the regional distribution of plant species. Moreover, there is speculation that rising temperatures and heightened carbon dioxide levels will accelerate the photosynthesis and growth rates of plants. Less well known is the critical role that vegetation will play in the carbon cycle and global warming. Scientists have carefully scrutinized and compared the amount of carbon dioxide released by fossil fuel burning to the rate of carbon dioxide buildup in the atmosphere and the amount absorbed by the oceans and vegetated land surfaces. They have concluded that over the past 15 years, approximately one-quarter of industrial carbon dioxide emissions have been absorbed and stored by the vast vegetated areas of the Northern Hemisphere, primarily the boreal and temperate forests of North America and Eurasia.

Normally, vegetation takes in carbon dioxide from the atmosphere and combines it with water to produce simple carbon compounds. This process, known as photosynthesis, is the basic biological process that powers the biosphere by removing carbon dioxide from the atmosphere and fixing it into biological material and soil compounds. Plants and animals effectively “burn” carbohydrates (and other products derived from them) in respiration. This yields energy for metabolism and renders the carbohydrate “fuel” back down to water and carbon dioxide. Decomposition by fungi and bacteria also breaks down the carbohydrates by using dead biological material as a working substance. Together, respiration and decomposition return the biologically-fixed carbon back to the atmosphere, completing the carbon cycle.

Over the past two decades, global vegetation has been affected by the increases in carbon dioxide by taking in more carbon dioxide and storing the fixed carbon in biomass or soil than it is releasing by respiration and decomposition. Why is this? Over the same period, air temperatures over the land have increased, resulting in a lengthened growing season in the northern and mid-latitudes. In fact, it seems that the northern spring now arrives approximately a week earlier than it did 20 years ago (Figure 2). Therefore, a gradual and slight warming seems to have favored photosynthesis over respiration-decomposition with far-reaching effects on the global carbon balance, as approximately one-quarter of our industrially-emitted carbon dioxide is now being fixed and stored by the vegetation. If this trend continues, the severity and onset of global warming might be delayed as increasing amounts of carbon dioxide are removed from the atmosphere and stored. However, some scientists warn that in the future, the biosphere could flip from being a net carbon sink (removing carbon dioxide) to a net carbon source (releasing carbon dioxide) over the next century.

Evapotranspiration and Greenhouse Warming

In addition to the carbon cycle, vegetation plays a direct role in other aspects of the Earth's climate. Green leaves are relatively dark, allowing for vegetated land to absorb more of the Sun's energy than light-colored deserts or snow-covered surfaces, which reflect most incoming solar radiation. Vegetation takes up water from the soil and releases it back to the atmosphere as water vapor, a process called "evapotranspiration." New studies suggest that higher levels of carbon dioxide in the atmosphere, coupled with higher temperatures, could alter evapotranspiration rates, which would impact both the hydrological cycle as well as land plant biomes.

During photosynthesis, thousands of tiny valve-like pores (called "stomates") on a plant's green leaves open up to allow carbon dioxide to flow into the leaf interior. Consequently, water lining the stomatal cavity can escape from inside the leaf out to the open air. This flow of water into the atmosphere acts to cool the land surface. As the water in the leaf is depleted, it is replaced by a flow of liquid water taken up from the soil by the plant's root system. Plants appear to continuously modulate the width of their stomates so as to get a maximum rate of photosynthesis for a minimum loss of water.

As concentrations of atmospheric carbon dioxide increase, plants may be able to reduce their evapotranspiration rates (water loss) to cause no reduction, or maybe even a slight increase, in photosynthesis. Some studies have modeled this effect and calculate that as carbon dioxide increases, evapotranspiration erasure over the continents will decrease, effectively reducing the amount of water vapor in the atmosphere. If this happens and greenhouse warming will be further amplified over the tropical land areas by as much as 50 percent above the predicted greenhouse warming effect alone (Figure 3).

Plants on the Move

A changing climate could cause some migration of plant biomes. For example, under a warming climate we might expect the northern boreal forests in Canada, Alaska and Siberia to creep northwards and replace the treeless tundra. This migration would be associated with changes in evapotranspiration, changes in how

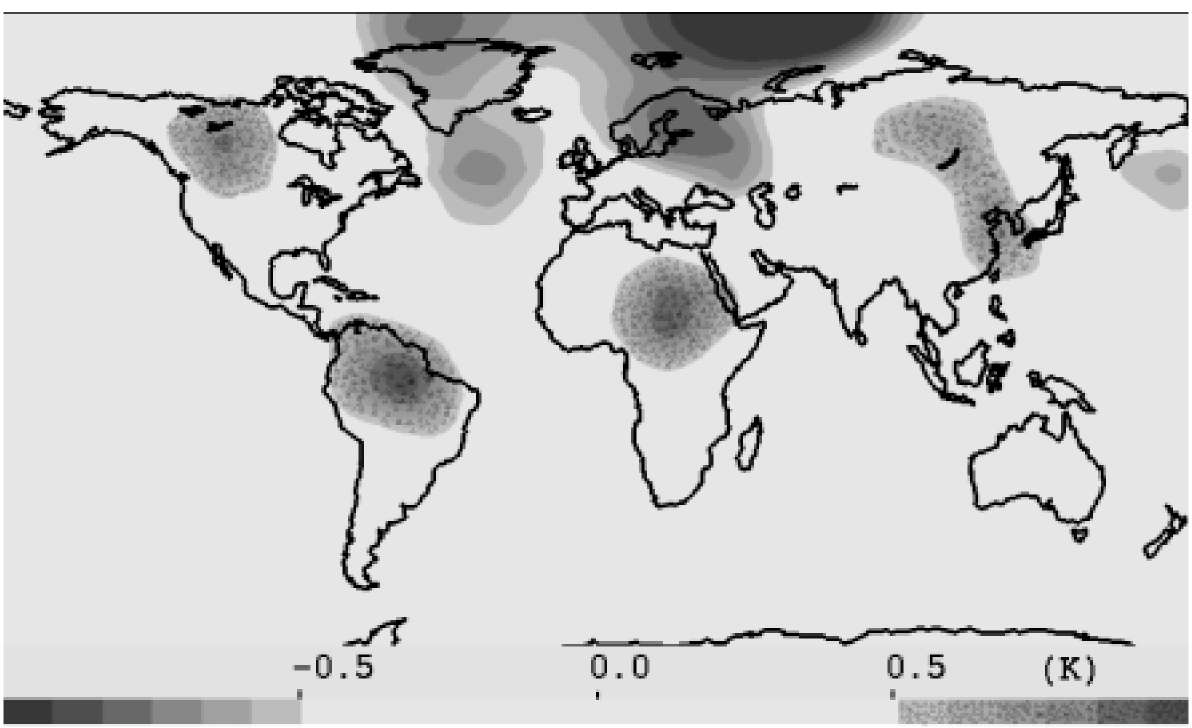

Figure 3. Computer model calculation of the effect of carbon dioxide on plant physiology and global climate. As carbon dioxide increases, vegetation may evaporate less water which would cause the land to heat up. This map shows additional heating (over and above the conventional carbon dioxide greenhouse effect) over the continents (dotted contours) due to this phenomenon, for doubled current carbon dioxide concentrations (700 ppm).

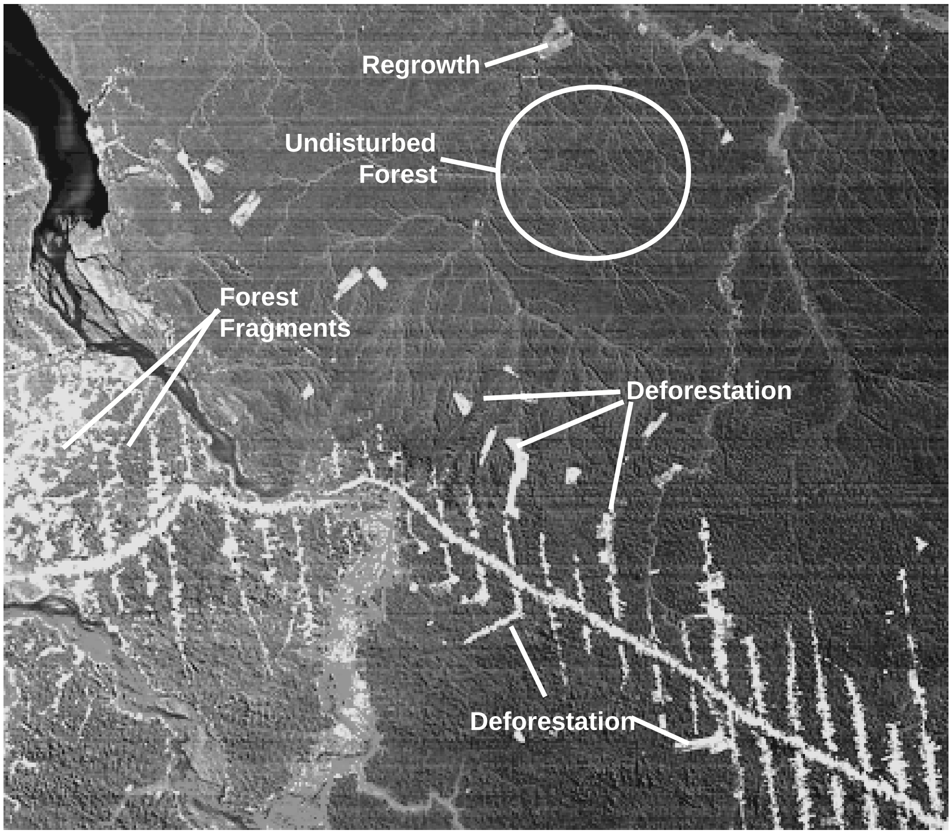

Figure 4. Satellite image of deforestation in the Amazon region, taken from the Brazilian state of Para on July 15, 1986. The dark areas are forest, the white is deforested areas, and the gray is regrowth. The pattern of deforestation spreading along roads is obvious in the lower half of the image. Scattered larger clearings can be seen near the center of the image.

much sunlight is reflected by the surface, and changes in "aerodynamic roughness" (which refers to the fact that different vegetation types have varying effects on wind patterns)—all of which will directly impact the local climate.

There is also anthropogenic (human-induced) interaction with plant biomes. Humankind has already set in place vast areas of cropland in the mid-latitudes, and deforestation continues in the tropics as developing nations try to provide for their populations. While these anthropogenic changes in the biomes are significant, especially with regard to species diversity, it is likely that they play less critical roles in the carbon cycle and global climate. But, monitoring these changes to the biosphere is vital to our understanding of how humans may be affecting other species on this planet.

Snow and Ice

In addition to land vegetation, other surface features are expected to change that require continuous monitoring from orbit. Snow and ice are critical players in determining high-latitude climates as many increased-carbon dioxide climate simulations predict a large-scale retreat of glaciers and permanent land ice, as well as a reduction in Northern Hemisphere snowfall. Changes in snow and ice cover can have profound effects on the climate system, as snow and ice reflect most of the incoming solar radiation. Thus, their replacement by dark vegetation or bare rock would act to reinforce a warming trend.

Terra and Landsat 7 Land Surface Observations

The extent, type, and health of global vegetation will be a key factor in determining the continental climates and the rate of increase of atmospheric carbon dioxide in the near future. To understand the important processes affected by vegetation and how these processes will influence the future state of the Earth, we need to develop improved predictive computer simulation models of the Earth's climate and biosphere. To make these models work realistically we need to know more about the distribution and season changes of the world's vegetation, as well as the exchanges of water and carbon between land vegetation and the atmosphere. The only practical way to do this consistently, continuously, and globally is through satellite remote sensing. Satellite instruments have already been used to detect changes in photosynthetic capacity, vegetation type, and growing season dynamics.

Terra and Landsat 7 will provide scientists with powerful tools for monitoring the Earth's biosphere. Terra instruments such as the Moderate-resolution Imaging Spectroradiometer (MODIS) and the Multi-angle Imaging Spectroradiometer (MISR) will provide continuous global coverage, permitting a thorough study of seasonal and inter-annual changes in land vegetation. The high-resolution Advanced Spaceborne Thermal

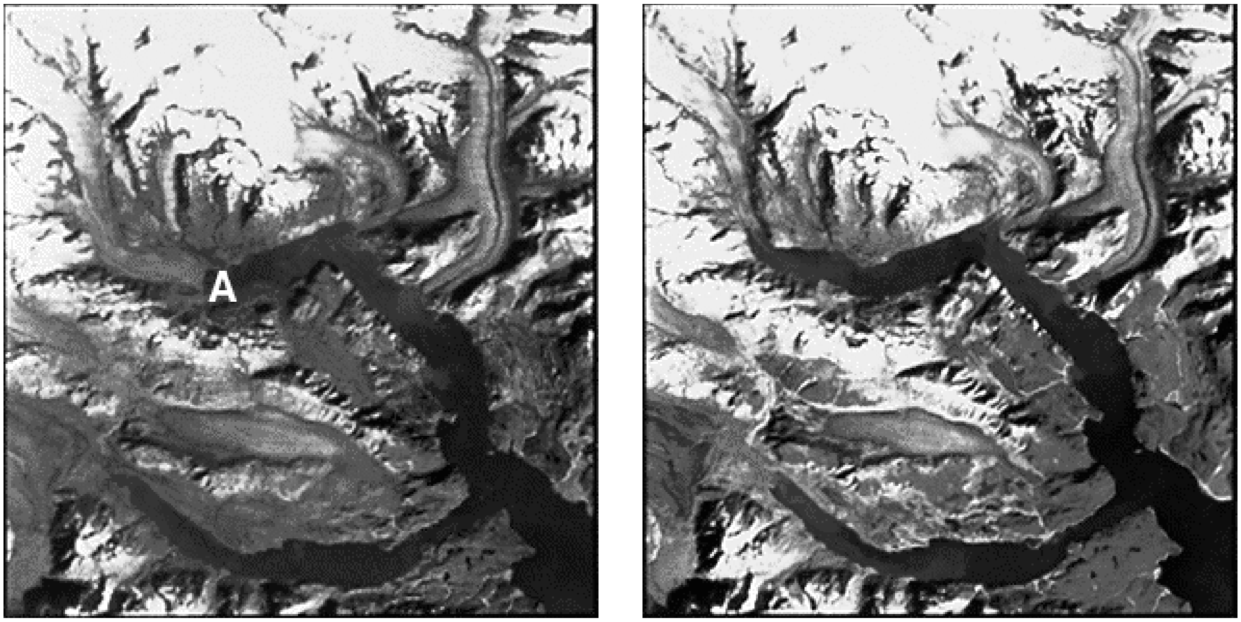

Figure 5. These Landsat images, acquired 13 years apart, show the retreat of the Muir Glacier (A) in southeastern Alaska. Between Sep. 12, 1973 (left image) and Sep. 6, 1986 (right image), the Muir Glacier retreated to the northwest more than 7 km.

Emission and Reflection Radiometer (ASTER, aboard Terra) and Enhanced Thematic Mapper (ETM+, aboard Landsat 7) instruments will provide detailed information about selected areas of special interest around the world; for example, areas undergoing intense deforestation (Figure 4). Using the data from these instruments, scientists will use computer models to study the effects of a changing climate on global vegetation and the Earth's biosphere.

The MODIS and MISR instruments on the Terra satellite will provide global monitoring of snow and ice extent, while the ASTER and ETM+ instruments will yield high-resolution images of snow and ice boundaries and glacier retreat sites (Figure 5). ASTER and ETM+ will also enable us to monitor inland waters, lakes, rivers and floodplains. (Hydrologists and meteorologists currently do not have access to global flood data.) Similarly, changes in the world's coastal zones and coral reefs will be monitored with these high-resolution instruments.

The Terra Spacecraft

Terra is the flagship of the Earth Observing System (EOS), a series of spacecraft to observe the Earth from the unique vantage point of space. Focused on key measurements identified by a consensus of U.S. and international scientists, EOS will enable research on the complex interactions of Earth’s land, ocean, air, ice and life systems.

Terra will circle the Earth in an orbit that descends perpendicularly across the equator each day at 10:30 a.m. local time, when cloud cover is at a minimum and the space-based view of the surface is least obstructed. Each individual swath of measurements can be compiled into global images as frequently as every two days. Over a month or more, in combination with measurements from other polar orbiting satellites, Terra measurements will provide accurate monthly-mean climate assessments that can be compared with computer model simulations and predictions.

The Earth Observing System has three major components: the EOS spacecraft, an advanced ground-based computer network for processing, storing, and distributing the resulting data (the EOS Data and Information System); and teams of scientists and applications specialists who will study the data and help users in industry, universities and the public apply it to issues ranging from agriculture to urban planning.

Additional information on NASA’s Terra mission can be found on the World Wide Web at http://terra.nasa.gov.